Update for the Balloon Array for RBSP Relativistic Electron Losses (BARREL) Mission

B.R. Anderson[1], R.M. Millan[1], M.P. McCarthy[2], J.G. Sample[3], D.M. Smith[4], K.B. Yando[1], L.A. Woodger[1], M.D. Comess[4], A.X. Liang[4], A.N. Baker[2], J.G. Hewitt[1], R.P. Lin[3], M.K. Hudson[1]

1. Dept. of Physics and Astronomy, Dartmouth College .
2. Dept. of Earth and Space Sciences, University of Washington .
3. Space Sciences Lab, U. C. Berkeley .
4. Dept. of Physics and SCIPP, U. C. Santa Cruz .

Abstract

BARREL is a multiple-balloon investigation that will study electron losses from Earth's Radiation Belts. Atmospheric losses of relativistic electrons play an important role in radiation belt dynamics; precipitation into the atmosphere may even completely deplete the radiation belts during the main phase of some geomagnetic storms. BARREL will consist of Antarctic balloon campaigns conducted in Austral summers of 2012-2013 and 2013-2014 during the RBSP mission. During each campaign, a total of 20 small (~20 kg) balloon payloads will be launched to an altitude of 30-35 km to maintain an array of 5-8 payloads extending across up to 8 hours of magnetic local time for 40 days. Each balloon will carry a NaI scintillator to measure the bremsstrahlung X-rays produced by precipitating relativistic electrons as they collide with neutrals in Earth's atmosphere.

We present an overview of the BARREL investigation and provide a brief description of two BARREL test campaigns. First, in December 2008, a BARREL prototype instrument was launched from McMurdo, Antarctica and carried for 54 days at an altitude of 34 km on NASA's new superpressure balloon. Observations of relativistic electron precipitation were made during a small geomagnetic storm on Feb. 14-18, 2009. Second, in December 2009, four BARREL prototype payloads were hand-launched from McMurdo, Antarctica. The BARREL team led the launches with support from the NASA Columbia Scientific Balloon Facility (CSBF). Equipment was tested in various configurations, providing important feedback for improvements. In addition, a third test campaign is currently being undertaken during December 2010.

BARREL is the first Living with a Star Geospace Mission of Opportunity and will support NASA's Radiation Belt Storm Probes (RBSP) mission, which is set to launch in May 2012. Antarctic operations for the 2008 and 2009 balloon campaigns were supported by the National Science Foundation.

Radiation Belt Variability

• The flux of relativistic electrons in Earth's radiation belts is highly variable (Figure 1a).
• Catastrophic depletions of the trapped population are often observed (Figure 1b).
• Rapid (~hours) decreases in the >2 MeV radiation belts electron flux have been attributed to precipitation into the atmosphere [Green et al., 2004; Millan et al., 2007]

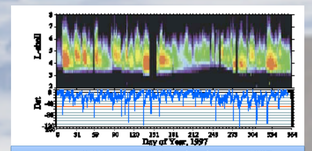

Figure 1a: 1.2-2.4 MeV electron flux for Year 1997 measured by the Polar spacecraft [Reeves et al., 2003]

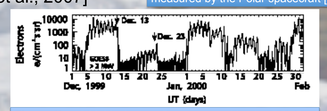

Figure 1b: >2 MeV electron flux measured by the GOES geosynchronous spacecraft [Onsager et al., 2002]

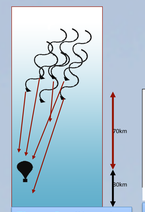

Figure 2a: Observing method: Precipitating electrons produce X-rays that penetrate to stratospheric balloon altitudes.

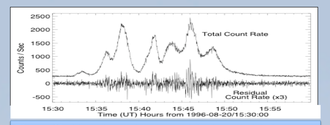

Figure 2b: X-ray burst due to precipitating relativistic electrons observed in 1996 over Kiruna, Sweden (Foat et al., 1998).

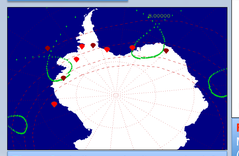

Figure 3a: balloons, simultaneously aloft, measure precipitation in conjunction with RBSP (green trace is one of the RBSP spacecraft footprints).

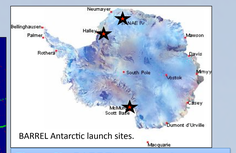

Figure 3b: BARREL launches from McMurdo Station (USA), SANAE IV (South Africa), and Halley Bay (UK)

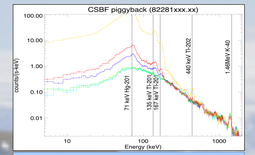

Figure 4 (above): 5-min spectrum accumulations prior to CSBF hangtest. Lower 2 traces show expected background count spectrum. Upper 3 traces, with elevated count rates (100X) for energy <100keV, show the presence of a person who recently ingested thallium-201 (half-life of 3 days) as part of a medical diagnostic procedure. "Radioactive Man"

Figure 5 (left): Aluminum scintillator housing contains PMT coupled to Sodium Iodide (NaI) crystal with gel

Figure 6 (right): Magnetometer

BARREL Key Elements and Method

- Measure precipitating electrons using detectors sensitive to their bremsstrahlung X-ray emissions (Figures 2a and 2b).
- Electron energy and flux are inferred from measurements of X-ray spectrum [Johns and Lin, 1992; Smith et al., 1995]
- Two Antarctic balloon campaigns obtain RBSP spacecraft conjunctions in two local time sectors
- 40 Long Duration Balloon (LDB) flights to obtain 200 hours of conjunctions with RBSP spacecraft
  - >300 duskside MeV events (10 in conjunction with RBSP)
  - ~80 hours of microburst precipitation (3 hours in conjunction with RBSP)
- Balloon payload array provides multi-point measurements (Figure 3)
  - removes spatial-temporal ambiguity
  - determines total electron loss rate
  - measures spatial scale of precipitation
- Each payload carried to 30-35 km altitude on 300,000 cu. ft. balloon
- Real-time measurements of electron precipitation disseminated via web.
- Conjunctions with RBSP allow for combining observations of precipitation with spacecraft plasma wave and energetic particle measurements (Figure 3)
  - Validate methods that use RBSP data alone to model losses

BARREL Instrumentation

- Primary Instrument: 3"x 3" NaI Scintillator (Figure 5)
  - Energy Range: 20 keV – 7 MeV
  - Eff. Area @1 MeV : 16cm^2 (photopeak)
  - Energy resolution: 10% FWHM @ 1MeV
  - Time resolution: 50 ms with GPS
- DC Magnetometer (Figure 6)
  - Sensitivity: <50 nT, 3 sigma
- GPS – Trimble Lassen SQ
- Payload size: 3' x 2' x 2'
- Weight: ~20 kg (45 lbs)
- Power: ~8 W provided by solar power
- Telemetry: ~2kbits/s provided by Iridium satellite network

BARREL Test Flight Results

December 2008 Piggyback Flight (Figures 7, 8)
- Flight test of BARREL prototype systems aboard CSBF superpressure Ultra Long Duration Balloon (ULDB)
- Launch: December 27, 2008
- 110,000 ft (~34 km)
- All systems performed nominally for the ~54 day flight
- Science data successfully taken of the small geomagnetic storm on Feb. 14, 2009

December 2009 Test Flights (Figures 9, 10)
- Four successful launches by BARREL team members on December 2, 5, 15, 17
- Each flight launched to 120,000 – 121,000 ft (36.6 – 37 km)
- All flight systems performed nominally except for solar panels
- Various configurations of solar panels tested
  - Flights 1 and 2 launched with all four solar panels "up" around the core of the payload, symmetrically
  - Flight 3 launched with no solar panels (extra battery power on payload)
  - Flight 4 launched with two solar panels "up" and two solar panels lowered below the core of the payload (Similarly to Figures 11, 12)

December 2010 Test Flights (In Progress) (Figures 11, 12)
- Two payloads are ready to launch, as of the printing of this poster
- We are testing two different kinds of solar panels
  - SunCat (Figure 11)
  - MEER Industries (Figure 12)

BARREL Schedule

- December 2008: Piggyback flight launched from McMurdo, Antarctica
- December 2009: Four-balloon test campaign launched from McMurdo
- December 2010: Second test campaign of 2 balloons launched from McMurdo
- 2011-2012: Fabrication, integration, and testing of BARREL payloads
- May 2012: RBSP launch
- 2012-13 and 2013-14: Two campaigns of 20 balloons each to launch from South African National Antarctic Expedition (SANAE IV) and Halley Bay (UK), during the Antarctic summer (Dec-February)

BARREL Science Objectives

BARREL will investigate both duskside and microburst precipitation in conjunction with observations from NASA's Radiation Belt Storm Probes (RBSP) Mission.

- Determine electron loss rate during specific RBSP relativistic electron events
  - Simultaneously measure precipitation over range of magnetic local times (MLT)
- Directly test models of wave-particle interactions
  - Combine measurements of precipitation with in situ RBSP plasma waves and particles
- Determine relative importance of different classes of precipitation
  - Occurrence probability maps in L-value (radial distance) and MLT
- Determine spatial extent and large-scale structure of precipitation
  - Multi-point measurements provide large-scale coverage and resolve spatial-temporal ambiguity

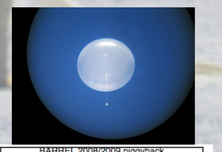

Figure 7 (top): NASA 7 million cu ft superpressure balloon at float altitude. BARREL test payload is on CSBF gondola hanging below the balloon. (Photo by D. Gregory)

Figure 8 (bottom): Trajectory for the piggyback flight launched from McMurdo, Antarctica on a NASA superpressure balloon, Dec. 2008

Figure 9: Launch of BARREL 300,000 cu ft balloon on December 5, 2009 from McMurdo. Same launch as background photo of poster. (Photo by N. Potts)

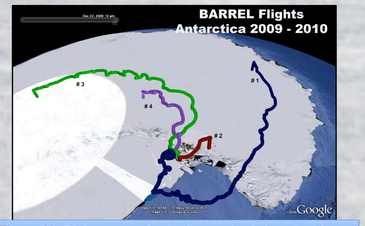

Figure 10: Flight patterns for the four payloads launched from McMurdo, Antarctica as part of the 2009 test campaign.

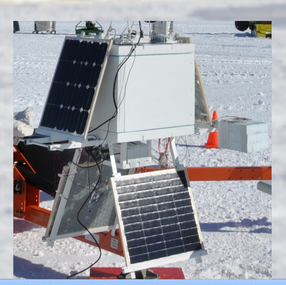

Figure 11: McMurdo Station, November 27, 2010. Payload with SunCat solar panels outside during a full systems test. (Photo by B. Anderson)

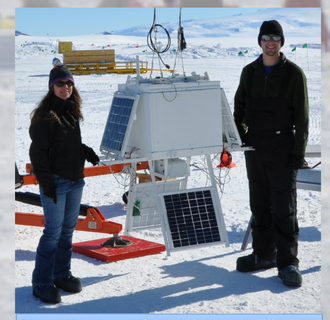

Figure 12: McMurdo Station, November 27, 2010. Payload with Meer solar panels, two of which are "up" around the core of the structure and two lowered below the core. (Photo by L. Schmick)

Acknowledgements: BARREL development is supported by the NASA Living with a Star Program. Additional support for test campaign operations at McMurdo is provided by the NSF Office of Polar Programs. Launch support is provided by the Columbia Scientific Balloon Facility. Further support will be provided by the British Antarctic Survey and the South African National Antarctic Program.
Background photo by N. Potts, taken on December 5, 2009 of BARREL launch #2 from McMurdo, Antarctica.